Black Cherry Health and Mortality on the Allegheny National Forest

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INTRODUCTION

Black cherry, *Prunus serotina* Ehrh., is a keystone species in the Allegheny hardwood forest with high timber value and a vital role in sustaining wildlife communities and ecosystem diversity (Marquis 1990). During the past decade persistent concerns have been expressed by foresters and land managers regarding black cherry crown condition, mortality, and lack of periodic masting and seed production. On the Allegheny National Forest (ANF), a network of 188 Forest Health Monitoring (FHM) plots was established in the late 1990s and early 2000s to address a range of forest health issues (Morin et al. 2006). Our project used a subset of these FHM plots with a black cherry component to assess recent crown condition, mortality, and regeneration across the ANF. The objectives of this project were to assess the current status of black cherry, to identify potential factors that could be related to black cherry health status, and to provide land managers with guidance regarding stands most susceptible to deteriorating crown condition and mortality.

BACKGROUND

The Allegheny National Forest and surrounding state and private forests have experienced multiple disturbances and stressors, primarily from defoliating insects over the past several decades. Over 85% of the ANF was defoliated at least once during the 16-year period from 1984 to 1999 based on an area-wide GIS analysis (Morin et al. 2004). The primary defoliating insects in this period were elm spanworm (*Ennomos subsignarius*), cherry scallop shell moth (CSSM) (*Hydria prunivorata*), and gypsy moth (*Lymantria dispar*). The elm spanworm defoliations from 1991-1994 involved multiple host species, but black cherry crown dieback increased significantly for trees defoliated 2 or 3 times compared to those defoliated once (Morin et al. 2004). The elm spanworm outbreak was immediately followed by an outbreak of CSSM from 1993 to 1996. In 1995 CSSM defoliated black cherry on more than 250,000 acres on the ANF. This defoliator primarily attacks black cherry and mortality of trees defoliated 2 or 3 times increased to 17.4% compared with only 5.6% for trees defoliated once (Morin et al. 2004).

More recently, Moderate Resolution Imaging Spectroradiometer (MODIS, https://modis.gsfc.nasa.gov) and the Forest Disturbance Monitor detected multi-year wide-scale defoliation of black cherry across northwestern Pennsylvania during the 2011 and 2012 growing seasons. Approximately 11,440 acres of detectable change were identified in 2011 and 20,572 acres in 2012 (Wolf and Turcotte 2013; Forest Health Protection https://foresthealth.fs.usda.gov/FDM). Ground verification showed that fall webworm (FWW), (*Hyphantria cunea*), a late season defoliator, was the defoliating agent and primarily attacked black cherry causing severe injury in multiple years (Wolf and Turcotte 2011). The extent and severity of the fall webworm defoliations had not been identified or detected in the National FHM plot network. However, the MODIS system clearly identified areas on the ANF affected by fall webworm in 2011 and 2012. The geographic extent and severity of the defoliation appeared worse in 2012 than in 2011. Only minor defoliation occurred in 2013.

A new outbreak of CSSM occurred in 2015 during the second year of this survey. CSSM is a mid-season defoliator that feeds gregariously and knits leaves together into a tube like structure where they feed on the leaf epidermis. Leaves turn brown, desiccate, and abscise. Subsequent attacks by secondary insects and pathogens combined with periodic droughts and late spring frosts may make black cherry more susceptible or less resilient to repeated late season defoliations and other stressors. Assessing the consequences of these latest defoliation events and identifying sites where black cherry may be most vulnerable will help land managers prioritize areas for treatment. Assessing crown condition and its implication for flowering and seed production will likewise help land managers be strategic in efforts to regenerate black cherry, including actively managing Allegheny hardwood forests in declining areas to capitalize on pulses of natural seedling regeneration.

METHODS

The amount of black cherry basal area per acre in the earlier two FHM surveys (1998-2001 and 2002-2006) was used to select plots with black cherry. We selected 102 plots with black cherry to re-survey during 2014 to 2016 field seasons. Based on the earlier surveys, black cherry basal area ranged from 5 ft^2/acre to 135 ft^2/acre. A GIS database was used to categorize these FHM plots with black cherry into one of nine categories representing different defoliation events and frequencies of disturbance from FWW defoliation, CSSM defoliation, and combinations of these defoliations. Data collection began with 49 plots sampled in 2014, 48 plots sampled in 2015, and 5 plots in 2016 for a total of 102 plots (**Fig. 1**). Overstory and understory plot data were collected on the four FHM subplots at a plot center.

In addition to the five new plots evaluated in 2016, 16 plots in or within 100 m of a mapped 2015 CSSM defoliation polygon were re-visited in 2016 to assess 2015 defoliation impacts (June) and estimate the severity of any new 2016 defoliation (late July) (**Fig.2**).

The third component of the 2016 black cherry health assessment involved selecting the 16 most healthy black cherry plots and contrasting conditions in these plots with the 16 least healthy black cherry plots. These 32 plots were selected based on the mean black cherry crown vigor assessments from 2014. In 2016 the plots were revisited to assess black cherry crown health and to sample mineral soils in each subplot for assessment of soil physical and chemical properties (**Fig. 3**). The objective of this approach was to identify potential contrasting factors related to the differences in black cherry health between these two groups of plots.

Crown Health Measures: All field personnel were trained by Forest Inventory and Analysis raters in crown health assessment measures. These focused on estimates of uncompacted live crown ratio, crown density, and fine twig dieback. Crews also estimated crown vigor (1: healthy < 10% dieback or other malady; 2: light decline, 10-25% dieback or portions of the crown missing; 3: moderate decline, 26 to 50% dieback or portions of the crown missing; 4: severe decline, > 50% of the crown with dieback or with portions missing; 5: standing dead) using definitions from the North American Maple Project (Cooke et al. 1996). Uncompacted live crown ratio is the length of the tree that supports live foliage relative to actual tree length or height and expressed as a percentage (Schomaker et al. 2007). Crown density refers to the amount of branches, foliage, and twigs that block light through the crown. It also integrates dead branches and dead tops that are part of the crown and are included in the percent crown density estimate (Schomaker et al. 2007). Crown dieback is estimated as the percent fine twig dieback in the upper and outer portions of the crown and only includes fine twigs that begin at the terminal portion of the branch

and proceeds toward the trunk. All crown health metrics except vigor are estimated to the nearest 5 percent class proceeding from 0, 5, 10, 15,.., to the 100 percent class.

2014-2016 Plots: The five new plots evaluated in 2016 were integrated with the 2014 and 2015 data, bringing the total plots assessed between 2014 and 2016 to 102 plots. Overstory health was evaluated for all trees ≥ 5 inches dbh in the four 24 foot radius subplots. Six-foot radius regeneration plots were sampled in each subplot. FHM overstory data from two earlier surveys of these plots (1998-2001, and, 2002-2006), were used to assess temporal changes in black cherry health. Because of plots added in the 2002-2006 cycle (plots only measured in one previous survey), only 97 plots were sampled in all three periods.

In addition, the influence of defoliation history, plot age, landform position, management history, and soil moisture variation on tree health was evaluated with GIS geodata based feature classes, and GIS derived estimates of soil moisture. To examine other factors potentially affecting black cherry health on the ANF, all the sampled FHM plots (n=102) were classified into one of three broad age-class categories: < 50 years old, 50-89 years old, and 90 to 120+ years old. Landform classifications for each plot included: plateau, side slope, foot slope and bottomland and these were examined to assess whether landform position affected black cherry health. FHM plots were also categorized with regard to defoliation history using feature classes within a geodatabase. Plots were categorized into one of four defoliation classes: 1) no known defoliations, 2) 1 to 3 FWW defoliations, 3) 1 to 3 CSSM defoliations (from 1993-1996), and 4) both FWW and CSSM defoliations. To assess the impact of management activities on black cherry, plots were also stratified according the ANF's management areas designated in the Allegheny National Forest Land and Resource Management Plan (Moore and Connelly 2007). Additionally, a stand management database was used to determine the history of management activities on or near each of the FHM plots. The health and mortality of black cherry was assessed after stratifying the plots into two groups based on a significant management activity (shelterwood harvest, removal cut, commercial thinning, site preparation) that occurred in the past 10 years (2004-2013), or similar activities that occurred more than 10 years ago.

To examine the influence of changing precipitation and moisture conditions, monthly Palmer Drought Severity Indices were used to create summary variables as expressions of drought and moisture excess for each plot over two ten-year periods: 1995-2004 and 2005-2014. For estimates of drought, a weighted cumulative drought severity index (CDSI) was calculated as the sum of the number of months with extreme drought (PDSI ≤ -4.0 X 3), plus the number of months with severe drought (PDSI -3.0 to -3.99 X 2), and the number of months with moderate drought (PDSI -2 to 2.99 X 1) over each ten-year period. Similarly, a cumulative moisture index (CMSI) was also derived as the sum of the number of months extremely moist (PDSI ≥ 4.0 X 3), plus the number of months very moist (PDSI 3.0-3.99 X 2), and the number of months unusually moist (PDSI 2.0 to 2.99 X 1) over each ten year period. Climatic data was downscaled from PRISM (Daly et al. 2008), to an 800 x 800 m grid using the Climate NA tool (Wang et al. 2016). From these data a cumulative drought severity index (CDSI) was derived for each plot and for each ten-year period (CDSI95_04 and CDSI05_14). Similarly, a cumulative moisture index (CMSI) was derived for each plot and for each ten-year period (CMSI95_04 and CMSI05_14). To compare plots with different drought or moisture stress, the median CMSI05_14 and the median CDSI05_15 were calculated and used to split the plots into two groups to compare drought and moisture stress effects on percent dead black cherry basal area in these respective plots.

2015 Defoliated Plots: The 2015 CSSM outbreak resulted in a significant change in priorities for black cherry health evaluations in 2016. To assess the impact of 2015 CSSM defoliations, 16 plots that were

known to have been defoliated or were within 100 meters of a mapped polygon with CSSM defoliation in 2015, were revisited in June 2016 to assess early season crown health. These 16 plots were re-visited again in late July to assess the 2016 defoliation status of black cherry trees. Field crews assessed crown health metrics including: crown vigor, uncompacted live crown ratio, fine twig dieback, and crown density. The amount of CSSM defoliation in 2016 was rated during the late July visit as the amount of brown leaves (0 = none or trace; 1 = 1-30%; 2 = 31 to 60%; 3 = more than 60% of crown with brown leaves). Brown leaves fall sometime after infestation and give the appearance of defoliation. The loss of these leaves cannot be distinguished from dieback, so dieback was rated in the late July assessment in 5% classes, and this value may include both fine twig dieback and CSSM defoliation where leaves have abscised and fallen from the tree crown.

Plots with and Contrasting Black Cherry Health: To assess and identify additional factors potentially affecting black cherry health, a comparison of the 16 healthiest FHM plots based on mean black cherry crown vigor assessments in 2014 and the 16 FHM plots with the poorest mean black cherry crown vigor in 2014 were re-visited in 2016. In addition to the assessment of crown health in these plots, soils were also sampled. At each FHM plot cluster, mineral soils were sampled by genetic horizon down to the upper 10 cm of the B horizon in each sub-plot. At each subplot a sample of A horizon, E horizon (if present), and the upper 10 cm of the B horizon was obtained and thickness of the A and E horizons was recorded. Soil samples from each of the four subplots were composited into a single sample for each horizon at each FHM plot cluster. Soil physical properties (percent sand, silt, and clay) were determined using the hydrometer method (Day 1965), and soil chemical properties were determined at the University of Maine Analytical Laboratory using the 'Forest Soil' package. Soil E horizons were not evaluated since few nutrients remain in these layers. Soil cations Ca, K, Mg, P, Al, Fe, Mn, Na, and Zn were determined by ICP after extraction with ammonium chloride. Soil pH, exchangeable acidity (by KCl extraction and titration), total C and N (by combustion at 1350° C), and percent organic matter (by loss on ignition) were also measured in each sample.

RESULTS

Temporal Changes in Black Cherry Health: Data from 97 plots sampled in three different cycles show an increasing trend in the number of standing dead stems (≥ 5 inches dbh) of black cherry (**Fig. 4**). About 16% of black cherry stems were standing dead in the earliest (1998-2001) survey. This increased to 22% of black cherry stems that are standing dead in 2014-2016, the most recent assessment. In comparison, standing dead for of all other species combined decreased from 12-14% in 1998-2001 and 2002-2006, to 11% in the 2014-2016 sample.

Similarly, the mean percent standing dead black cherry basal area per acre increased from about 8% in the 1998-2001 survey to almost 17% in the 2014-2016 survey (**Fig. 5**). The mean percent standing dead basal area of all other species combined decreased from 12-13% in the earlier two surveys to 9% in the 2014-2016 survey.

The mean number of standing dead black cherry trees per acre was 8.1 ± 1.2 in the 1998-2001 survey, 10.0 ±1.4 in 2002-2006, and 12.5 ±1.6 trees per acre in 2014-2016. The mean number of standing dead trees per acre of all other species combined was 16.9 ±1.4 in the 1998-2001 survey, 20.1 ±1.4 in 2002-2006, and 14.63 ±1.8 trees per acre in 2014-2016.

Standing dead black cherry basal area is concentrated in the sawtimber size class, trees ≥ 11 inches dbh (**Fig. 6**). Sawtimber black cherry mortality averaged 5 ft^2/acre, or 69% of the mean percent standing dead black cherry basal area per acre across the 102 plots. For pole timber, trees 5 to 10.9 inches dbh, mortality was considerably less at about 2.2 ft^2/acre, or 31% of mean standing dead black cherry basal area per acre.

Several crown condition metrics were used to assess crown health of trees in these plots. The uncompacted live crown ratio, crown density, and fine twig dieback ratings, originally rated in 5% classes, were all placed in broader categories for comparisons. Changes in the uncompacted live crown ratio (ratio of the portion of the tree with foliage to the total height of the tree, expressed as a percent) show major changes (**Fig. 7A**). In the earlier two surveys more than 60% of the black cherry basal area was in the 25 to 45% live crown ratio class. In the most recent, 2014-2016 survey, almost 60% of the black cherry basal area is in the smaller, 0-20%, live crown ratio class, indicating live crowns have become smaller. Crown density, the amount of light blocked by foliage and branches including dead branches and tops, also showed temporal variations (**Fig. 7B**). In the earlier two surveys, 40% (1998-2001) to 60% (2001-2006) of black cherry basal area was in the 50 to 70% crown density class. However, in the 2014-2016 survey, more than 70% of the black cherry basal area was in the 25-45% crown density class, meaning crowns have become less dense and may have more snag branches or portions of the crown that are missing. Most of the surveyed trees have small amounts of fine twig dieback (**Fig. 7C**) and 80% or more of the black cherry basal area was in the 0-20% dieback class in all three surveys. It should be noted that dieback estimates do not include snag branches or portions of the crown that are missing as these are included with the density estimate. The increase in the 95-100% dieback class in 2014-2015 includes standing dead trees noted previously.

Mortality in relation to other factors: Mean standing dead black cherry basal area per acre did not differ among the three age classes (**Fig. 8**), ranging from just over 15% to 16.6%. Most of the FHM plots (n=57) are in the oldest age class, 90-120 years, but the amount of standing dead black cherry basal area is not appreciably different in comparison with the other two younger age classes.

The mean percent standing dead black cherry basal area ranged from 12% in plots that had no recorded defoliations to 17.5% in plots defoliated 1-3 times by FWW (**Fig. 9**). FWW defoliations occurred most recently from 2011 to 2013. FWW is a late season defoliator and many trees were heavily (≥ 60%) defoliated for 2 to 3 successive years. The last major CSSM defoliations occurred from 1994 to 1996 and more than 250,000 acres were affected on the ANF in 1995, the peak year of defoliation. The plots defoliated by CSSM had about 16% of the black cherry basal area as standing dead. Plots with both FWW and CSSM defoliations did not indicate any additive effect and averaged 16.5 % standing dead black cherry basal area.

An assessment of mean standing dead black cherry basal area in relation to landform/slope position reveals considerable variation (**Table 1**). Mean percent standing dead black cherry basal area was greatest on foot slope plots (n=24), averaging 23.8%. Both the side slope and plateau top plots had considerably less standing dead black cherry basal area. Bottom slope plots were sparse (n=2) and no conclusions can be drawn from this small sample.

The relationship of black cherry health to different management goals was assessed by stratifying plots into major ANF management areas. For the even-aged management area (MA), 3.0, standing dead black cherry basal area averaged 8.2 ft^2/acre in the 65 plots within this management area. The remaining 37 plots were mostly within management area 2.2 (25 plots). This MA focuses on late structural linkages that link relatively large areas of older forests across the landscape with objective of maintaining structural features and continuity of the forest. Plots in this MA and 12 plots in some other management areas (MA 1.0, n=4; MA 5.2, n=2; MA 6.1, n=3; MA 7.2, n=2; MA 8.2, n=1) had 5.3 ft^2/acre of standing dead black cherry basal area **(Fig. 10)**. These 37 plots generally had less black cherry with overall basal area (live and dead) averaging 51 ft^2/acre while the 65 plots in MA 3.0 had an average of 61 ft^2/acre of black cherry.

Only 33 of the 102 plots had records of management activities. Most of these records showed activities that included salvage harvests, shelterwood cuts, removals, commercial thinning, or site preparation. Overall, managed plots had a lower amount of standing dead black cherry basal area 6.57 ft^2/acre or 13.2% compared with all 102 plots. For 23 of the 33 plots these management activities occurred more than 10 years ago (2003 or before) and the remaining 10 plots had management activities within the past 10 years (2004-2013). For the 23 plots with management activities more than 10 years ago, standing dead black cherry basal area averaged 7.9% or 4.6 ft^2/acre. For the 10 plots with more recent management, the standing dead black cherry basal area averaged 25.5% or 11.22 ft^2/acre. However, this greater mortality was driven by two plots with high black cherry mortality. One plot had a recent salvage harvest and 63% of the total black cherry basal area (22 of 35 ft^2/acre) was standing dead. The other plot with 100% standing dead black cherry basal area had only one black cherry tree in the sampled plot. Omitting these two plots gives a mean percent dead black cherry basal area of 11.3% or 9.3 ft^2/acre. The remaining 69 plots did not have records of management activities.

Cumulative drought and moisture indices were derived for two time periods (1995-2004 and 2005-2014) and show contrasting moisture and drought conditions in these different periods for these FHM plots. The CDSI average was 49 for 1995-2004 and only 5 for 2005-2014 indicating less severe drought conditions in the more recent 10-years (**Fig. 11**). Conversely, the CMSI averaged 71 from 1995 to 2004 for the FHM plots, but averaged 129 in the more recent 10-years. These modeled values indicate greater excess moisture affected these plots from 2005 to 2014. Plots stratified into contrasting groups based on the median CMSI value for the most recent 10 years showed that plots having the greatest moisture (CMSI > 134) had 13.7% (± 2.5, n=48) dead black cherry basal area compared with 16.3% (± 3.8, n=54) on plots having CMSI ≤ 134. Likewise there was little difference in the percent dead black cherry basal area based on the comparison of two groups stratified by the median CDSI (CDSI=4) for the most recent 10 years (2005-2014). Plots with CDSI > 4, indicating greater drought stress, averaged 14.6% (± 3.8, n=47) dead black cherry basal area, and plots with CDSI ≤ 4 averaged 15.4% (± 2.9, n=55) dead black cherry basal area.

Understory Conditions and Woody Regeneration: Seedling regeneration was evaluated on 6 foot radius plots established 15 feet east of plot centers in each of the four subplots in the FHM plot cluster. Established seedlings were limited by low light conditions in these mostly uncut FHM plots. Black cherry was the most abundant established seedling (stems ≥ 0.2 feet tall to < 1 inch dbh), but on only two plots, averaging 4610 seedlings/acre (**Fig. 12**). Red maple was the second most abundant (greatest number of seedlings/acre) and also was the most frequent woody stem to dominate established regeneration. Red maple was the dominant seedling on 53 plots with an average of over 4,400 seedlings/acre (**Fig. 12**). Established seedlings, sprouts, or root suckers of American beech occurred on 24 plots and averaged

about 2,500 stems/acre. Birch (*Betula* spp.) was the third most common dominant species group with about 2800 seedlings per acre, but occurring as the most abundant species on only 5 of the FHM plots. On the remaining 20 FHM plots only small amounts of other woody species were dominant. These included: muscle wood (CAR=*Carpinus caroliniana*), sugar maple (SM=*Acer saccharum*), choke cherry (*P. virginiana*), pignut hickory (*Carya glabra*), northern red oak (*Quercus rubra*), glossy buckthorn (*Frangula alnus*), striped maple (*A. pensylvanicum*), serviceberry (*Amelanchier* spp.), white ash (*Fraxinus Americana*), witch hazel (*Hamamelis virginiana*), and yellow birch (*B. allegheniensis*).

In addition to the number of established seedlings, the height and species of tallest seedling or sapling (≥ 0.2 feet tall to < 5 inches dbh) on each plot was recorded. American beech was the tallest stem on 50 of the FHM plots with an average height of 12.9 feet (**Fig. 13**). Sweet birch had the mean tallest stem, 16.3 feet, in 13 of the plots. Red maple had the tallest stem in only 9 of the plots with an average height of just over 10 feet. Black cherry was the tallest stem on only 5 plots, usually as a small sapling and averaging about 30 feet tall. Striped maple was the tallest stem on 8 plots averaging about 17 feet tall. While many of the remaining species had taller stems or saplings, they occurred in only six or fewer plots.

As an indicator of potential seed production and seed bank storage, new germinants or small seedlings < 0.2 feet tall were also tallied in the 6 foot regeneration plots. New germinants of black cherry were found in 53 of the FHM plots and averaged 860 seedlings/acre. Birch (*Betula* spp.) were observed in the plots, but both the number of seedlings, 553 per acre, and their frequency across all 102 plots, N=35, was low (**Fig. 14**).

2015 Defoliated Plots: Sixteen plots defoliated by CSSM in 2015 or within 100 m of a defoliation polygon were re-evaluated in June 2016 (see **Fig. 2** for the location of these 16 plots). Only modest changes in black cherry crown health were detectable in 2016. In 2014 and 2015, 27% (47 trees) of the 176 black cherry trees in these 16 plots were standing dead. By 2016 an additional tree had died and one previously dead tree was no longer standing. In the 2014 and 2015 crown assessments, only 7.4% or 13 trees had more than 25% crown dieback (vigor 3 and 4 trees) or other crown maladies (discoloration, snag branches). By June 2016, 22% (39 trees) had more than 25% crown dieback or other crown maladies. Changes in uncompacted live crown ratio, fine twig dieback, and crown density were not notably different by June 2016, compared with estimates from 2014 and 2015.

Black cherry trees in these plots were assessed a second time in late July 2016. By this time, some plots had current year infestations of CSSM. Leaf browning, the first conspicuous stage of CSSM defoliation, was detected in about 50% of the living black cherry trees while 50% were unaffected. More than 90% of the affected trees had only light, 1% to 30% defoliation in late July. Eleven black cherry trees, about 9%, were totally defoliated by late July. **Figure 15** shows examples of trees partly and totally defoliated by CSSM in 2016.

Plots with Contrasting Black Cherry Health: Sixteen plots with highest black cherry mean crown vigor and 16 plots with the lowest black cherry mean crown vigor were sampled to identify factors that could account for contrasting crown health (plot locations are shown in **Fig. 3)**. The percent of trees in five vigor classes (**Fig. 16**) show the contrast in cherry health between these plots. A total of 78, or 43%, of the black cherry trees on the least healthy plots were standing dead compared with 20 trees, or 11%, on the most healthy plots. The amount of standing dead black cherry basal area compared with the basal area of all

other species combined also shows the contrast between the health status of black cherry on these plots (**Fig. 17**). In the least healthy plots, 34%, or 21 ft^2/acre, of the black cherry basal area was standing dead while the most healthy plots had 7.8%, or 7 ft^2/acre, of standing dead black cherry basal area. The amount of standing dead basal area for all other species combined was modest, 4.2% to 7.1% for both groups of plots with contrasting black cherry health. This demonstrates a contrast in black cherry on these plots, but not for other tree species.

We examined the same range of factors used previously to see whether stand age, defoliation history, and slope position could account for differences in black cherry health. Most of the plots are in the 90-120 year age class or the 50 to 90 year age class (**Fig. 18**). Plot age does not appear to be a driving factor affecting black cherry health status. The high amount of dead black cherry basal area in the < 50 year age class for least healthy plots is driven by just two plots with relatively small amounts of black cherry.

Plots were also classified into one of four landform positions: plateau, side slope, foot slope, and bottom land. There was considerable variation in both the total amount of black cherry basal area and the amount of standing dead black cherry basal area across these landform positions (**Fig. 19**). While the least healthy plots on plateau positions had the highest amount of standing dead black cherry basal area, 24.0 ft^2/acre, the sparse number of plots does not permit a conclusive assessment. Foot and side slope plots also had considerable amounts of standing dead black cherry basal area in the least healthy plots. For the most healthy plots, foot slope plots had the greatest mean percent dead black cherry basal area, 6.4 ft^2/acre, across all landscape positions for this group (**Table 2**).

The total amount of black cherry basal area, live + dead trees (**Fig. 20**), suggests that foot and side slope sites with high amounts of black cherry basal area (> 70 ft^2/acre) are among the most susceptible to higher levels of black cherry mortality. Additionally, based on the analysis of age classes, older stands (90-120 years) in the foot and side slope positions would be most vulnerable to high levels of black cherry mortality. However, the lack of plots in other landscape positions and age classes, particularly plateau top sites, requires that this conclusion be considered tentative until more data are available.

Plot defoliation history was also used to assess the influence of past defoliation(s) on black cherry health in plots with contrasting health status (**Fig. 21)**. Defoliation classes included: 1) plots with no defoliation, 2) plots defoliated 1 to 3 times by fall webworm (FWW) only (usually from 2011-2013), 3) plots defoliated 1 to 3 times by cherry scallop shell moth (CSSM) (most records from 1994-1996), and 4), plots defoliated by both FWW and CSSM. Just as with the 102 plot data set, it is difficult to assess the relative impact of the CSSM and FWW defoliations (**Fig. 21**). There does not appear to be an additive effect of the defoliation, especially on the least healthy plots and the greatest amount of standing dead black cherry basal area, 35 ft^2/acre, is associated with the more recent FWW defoliated plots. On the most healthy plots, however, standing dead black cherry basal area is clearly greater (9.9 ft^2/acre) on plots having both FWW and CSSM defoliation. The period since the last CSSM outbreak, 20+ years, likely means that trees affected by those defoliations may be dead and down and thus do not appear in these analyses.

In summary, the contrast in black cherry health between these two sets of FHM plots is quite dramatic. However, the use of plot age, plot landform/slope position, or plot defoliation history provides only limited explanatory power to develop causal hypotheses to explain these differences in black cherry health.

Soil chemical and physical properties were evaluated for mineral soil samples of A and B horizons obtained from the plots with contrasting black cherry health. Soil textures of A horizon samples were loams, or sandy loams. The B horizon samples generally had less sand and more clay with textures that were clay loam. Statistical analyses (t –tests) to compare mean exchangeable concentrations of macro elements did not reveal substantial differences between the most healthy and least healthy plots except for exchangeable Mn in the A horizon samples (**Fig. 22**). Exchangeable Mn in soils from the most healthy plots averaged 232 mg/kg while Mn from the least healthy plots averaged 83 mg/kg. Other macronutrients did not differ significantly. However, Fe concentrations in A horizon samples from least healthy plots, averaged 93 mg/kg, and were greater than mean Fe concentrations, 67 mg/kg in samples from the most healthy plots. While this difference was not statistically significant, higher Fe concentrations may interfere with uptake of Mn. The most healthy plots also had slightly more exchangeable Ca, though the difference was not statistically significant.

A closer examination of A horizon Mn concentrations in foot and side slope plots shows that Mn concentrations for the most healthy side slope plots averaged 365 mg/kg while in the A horizons from the least healthy plots Mn averages 58 mg/kg. Mn concentrations for the most healthy foot slope stands averaged 134 mg/kg while Mn averages 73 in A horizons soils from the least healthy foot slope plots.

The percent organic matter, total percent nitrogen (N), and total percent carbon (C) did not differ significantly between the most healthy and the least healthy plots for both A horizon and B horizon samples (**Fig. 23**). The mean percent organic matter and mean total percent carbon were both greater on the most healthy plots, but the differences when compared with the least healthy plots were not statistically significant ($P > 0.05$).

SUMMARY AND CONCLUSIONS

Results of this study show inconclusive links to stand age, defoliation history, landform position, management activity, drought or excessive moisture stress, or soil physical and chemical properties that could account for the accumulation of black cherry mortality and the deterioration of cherry crown condition. There are, however, some hints as to factors that could be more thoroughly tested. These data suggest that older stands on lower back slope or foot slope landscape positions appear most vulnerable to decline and accumulated mortality. Plots in foot and side slope landscape positions with black cherry basal area averaging > 70 ft^2/acre are the most vulnerable to increased levels of black cherry mortality. The excessive moisture conditions over the past 10 years may also have a greater effect on trees in this landscape position. While A-horizon soil Mn concentrations were lower in the stands with poor black cherry health, more data is needed to fully test this relationship.

Comparisons of current conditions with previous surveys gives some indication of degree of change in black cherry health status. In the initial assessment of all 173 FHM plots surveyed from 1998 to 2001, 7.6% of the black cherry basal area was standing dead, or 2.7 ft^2/acre (Morin et al. 2006). It is important to note that data from the 173 plots surveyed from 1998-2001 used all plots so that plots with very little or no black cherry were included in this value. This earlier survey also found the crown condition of black cherry with higher percentages of trees with larger live crown ratios and greater crown density than found in the 2014-2016 survey of a sub-sample of these plots (102 plots, all with black cherry). Also, notably different from the 1998-2001 survey is the finding that most of the black cherry mortality was in the 5.5 – 9.9 inch

diameter class whereas the 2014-2016 survey found most of the mortality was associated with trees ≥ 11 inches dbh.

Other agencies with forest inventory data corroborate the changing the status of black cherry in other forests in Pennsylvania. Data from the Pennsylvania Bureau of Forestry Continuous Forest Inventory (CFI) plots have shown increased numbers of standing dead black cherry trees. In the most recent inventory from 2009-2013 over 30% of the black cherry stems ≥ 5 inches dbh were standing dead in Pennsylvania state forest plots sampled in the High Plateau and Allegheny Front physiographic sections (S. Lehman, personal communication). Similarly, the Pennsylvania Game Commission found more than 26% of the black cherry trees were standing dead in 322 CFI plots measured from 2011-2015 in the Deep Valleys physiographic section (P. Lupo, personal communication). For the ANF FHM plots, 23% of black cherry stems ≥ 5 inches dbh were standing dead in the 2014-2016 survey.

Over the past several decades black cherry has experienced a myriad of maladies including high wind events, ice storm injury, and multiple insect defoliation events (Morin et al. 2006). The effect of the older CSSM defoliations apparently has diminished substantially since the combined CSSM and FWW defoliated plots show no major increase in standing dead black cherry basal area, at 16.8%. However it should be noted that black cherry trees severely injured or killed by CSSM in the 1990s may no longer be standing in these plots, so the effects of these defoliations may be underestimated in the current data.

Both insect defoliations and major blowdown events are frequently quantified with aerial mapping. Black cherry is shallow rooted and susceptible to wind events (Hough 1965). Research conducted after a 2003 blowdown event found that in the preceding 10 years the plateau annually had an average of 11 high wind events and one tornado (National Climate Data Center 2005; Evans et al. 2007). These disturbances are highly dispersed, occur sporadically across the landscape, and are not well quantified in forest health monitoring data. The progression of American beech mortality associated with beech bark disease across the ANF has also created gaps that may make black cherry even more vulnerable to high wind events. These events create a patchwork of disturbance across the landscape that is difficult to record and quantify.

Much of the black cherry on the ANF is now over 100 years old and damage and injuries have accumulated on many trees. Defoliation stress and disturbance events may make black cherry more susceptible to attack by secondary organisms. These include cambial miners and bark beetles. Other research has shown that black cherry trees weakened by CSSM defoliation are commonly attacked by peach bark beetles, *Phloeotribus liminaris* and heavy attacks can result in black cherry mortality (Schultz and Allen 1977). More commonly, peach bark beetle and other cambium miners such as *Phytobia pruni* cause injuries that induce gum exudates and the formation of gum spots in black cherry xylem leading to degraded timber products (Hough 1963; Kulman 1964).

The changing status of black cherry presents significant challenges for forest managers. The ability to harvest mature timber and regenerate stands with species composition similar to the harvested stand is compromised by the lack of adequate seedling regeneration which, in part, may be related to poor cherry crown condition or health maladies. Managers will need to carefully assess the likelihood of success with regard to management practices. Black cherry will remain an economically and ecologically valuable species and concerted attention and adaptive management practices will likely produce methods to improve and sustain this valuable resource.

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Table 1. Mean percent standing dead black cherry basal area per acre by landform slope position.

Landform Slope Position	Number of Plots	% Dead Black Cherry BA/Acre (±se)
Bottom	2	13.5 (13)
Foot	24	23.8 (6.1)
Side	47	14.5 (3.4)
Plateau	29	11.7 (3.9)

Table 2. Mean amount of standing dead black cherry basal area (ft^2/acre) in four slope position classes in the 16 most healthy and 16 least healthy FHM plots.

Plot Status	Bottom	Foot	Side	Plateau
Most Healthy	0, n=1	6.4, n=5	3.1, n=6	4.2, n=4
Least Healthy	13.1, n=1	20.5, n=5	21.5, n=8	24.0, n=2

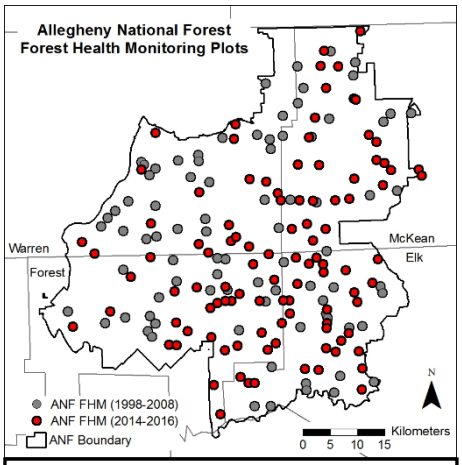

Figure 1. Forest health monitoring plots on the Allegheny National Forest. Red dots are plots sampled from 2014-2016.

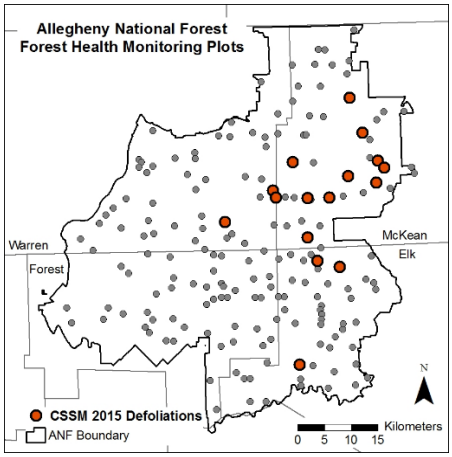

Figure 2. Sixteen plots (red dots) defoliated by cherry scallop shell moth in 2015.

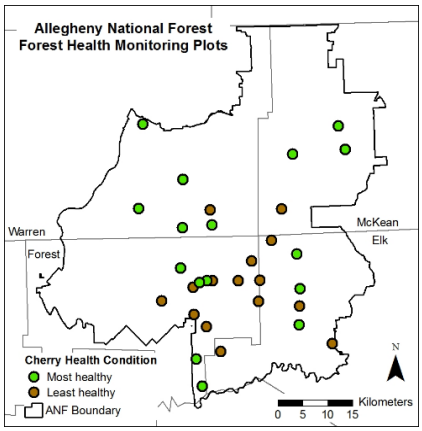

Figure 3. Sixteen FHM plots with the most healthy (green dots) and 16 FHM plots the least healthy (red dots) black cherry.

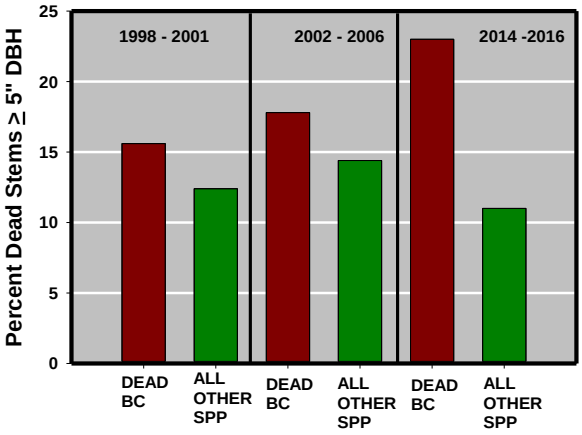

Figure 4. Percent standing dead stems (≥ 5 inches dbh) of black cherry and all other species combined in three time periods across 97 FHM plots.

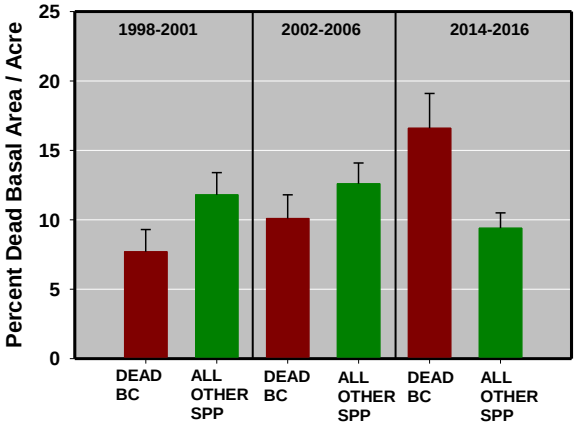

Figure 5. Percent standing dead black cherry basal area per acre and basal area per acre of all other species combined in three time periods across 97 FHM plots.

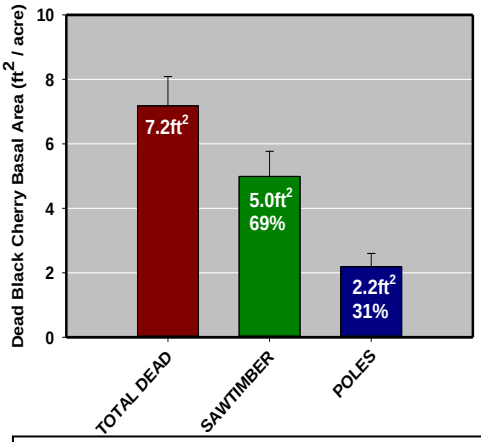

Figure 6. Mean standing dead black cherry basal area per acre (n=102) and amount standing dead in sawtimber (trees ≥ 11 inches dbh) and pole timber (trees 5 – 10.9 inches dbh) size classes.

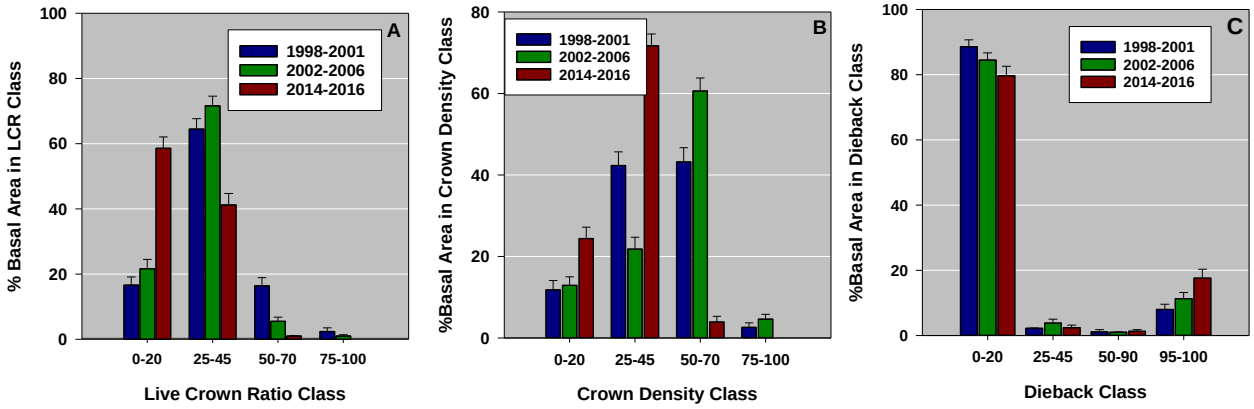

Figure 7. A) Mean percent of black cherry basal area in four live crown ratio classes in three different surveys, 1998-2001, 2002-2006, and 2014-2016; **B)** mean percent black cherry basal area in four crown density classes; and **C)** mean percent black cherry basal area in four fine twig dieback classes during three surveys.

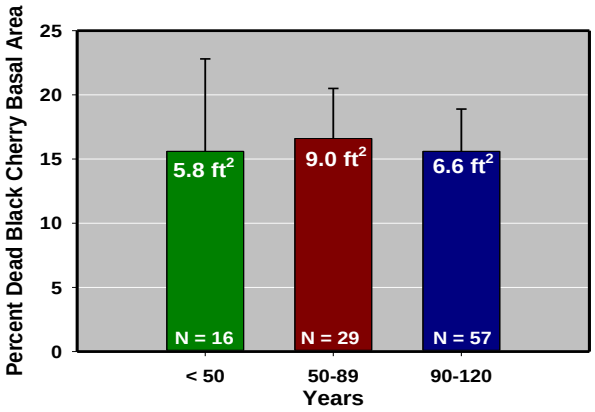

Figure 8. Mean percent standing dead black cherry basal area per acre by plot age classes.

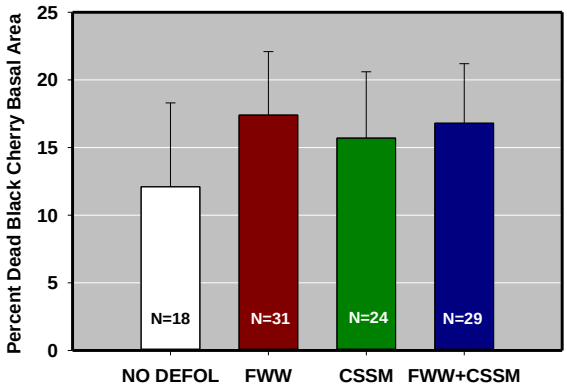

Figure 9. Mean percent standing dead black cherry basal area per acre in four defoliation classes.

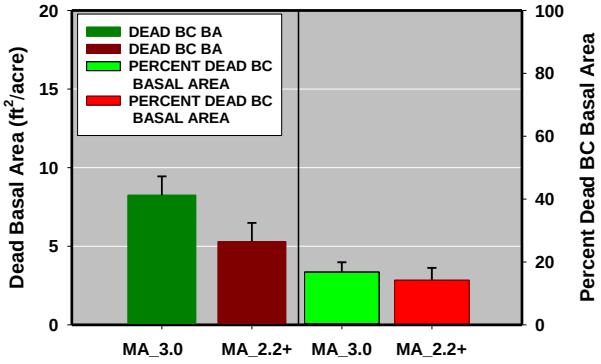

Figure 10. Standing dead black cherry basal area per acre and percent standing dead black cherry basal area in FHM plots by management areas (MA) on the ANF.

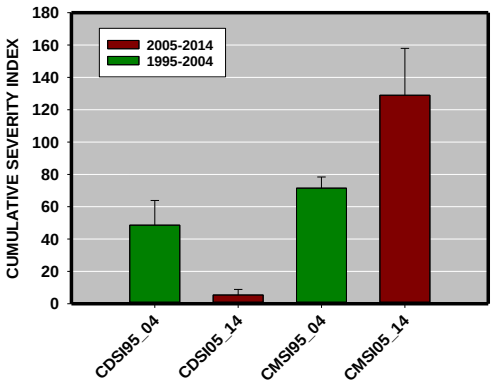

Figure 11. Mean and standard deviations of cumulative drought (CDSI) and moisture (CMSI) severity indices for FHM plots in 1995-2004 and 2005-2014.

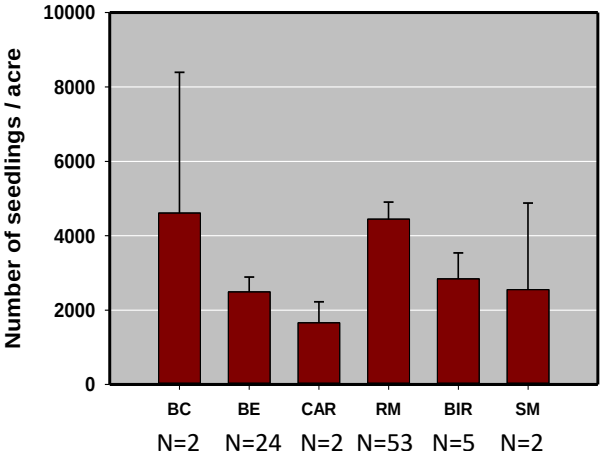

Figure 12. Most abundant woody seedling species on 102 FHM plots (expressed as mean number of seedlings, stems ≥ 0.2 feet tall and < 1.0 inch dbh, per acre).

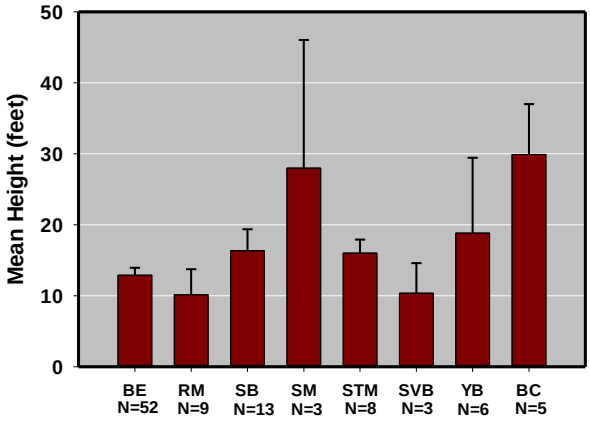

Figure 13. Mean height of the tallest seedling or sapling ≥ 0.2 feet tall to < 5 inches dbh on plots where they occurred.

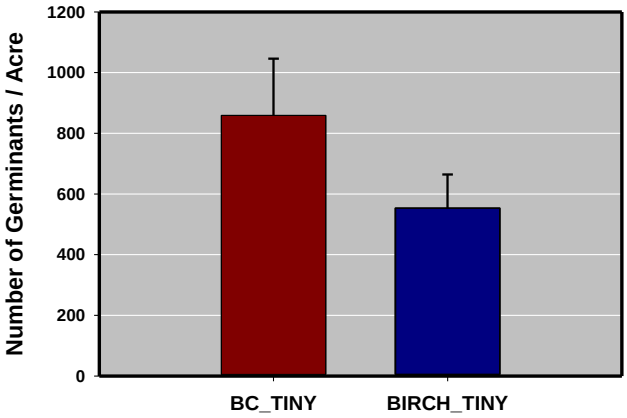

Figure 14. Mean number of black cherry and birch seedlings < 0.2 feet tall in FHM plots.

Figure 15. A) Partially defoliated black cherry tree; **B)** black cherry tree totally defoliated in 2016.

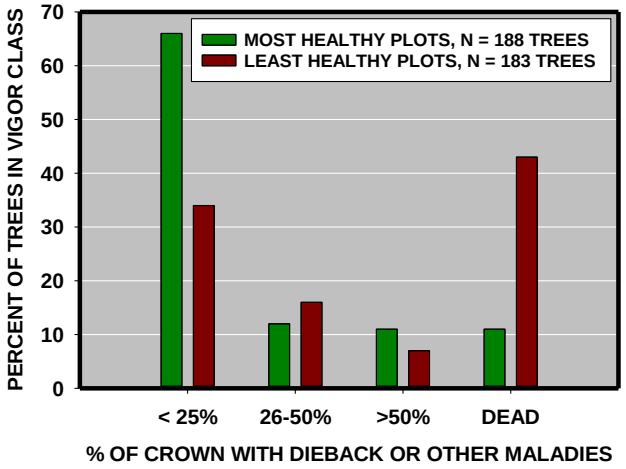

Figure 16. Percent of trees in each of 4 vigor classes for 16 of the most healthy and 16 of the least healthy FHM plots. Vigor classes 1 and 2 were combined into the < 25% class.

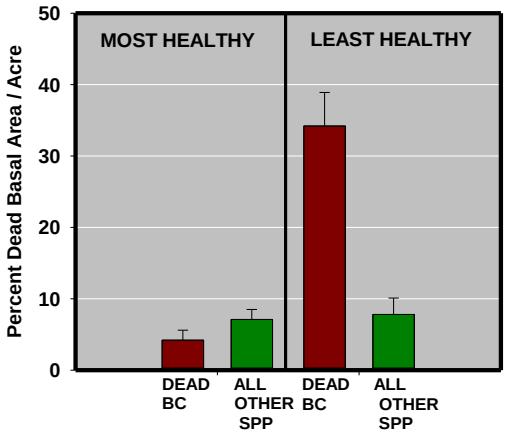

Figure 17. Percent standing dead black cherry basal area and all other species combined in the most (16) and least (16) healthy plots.

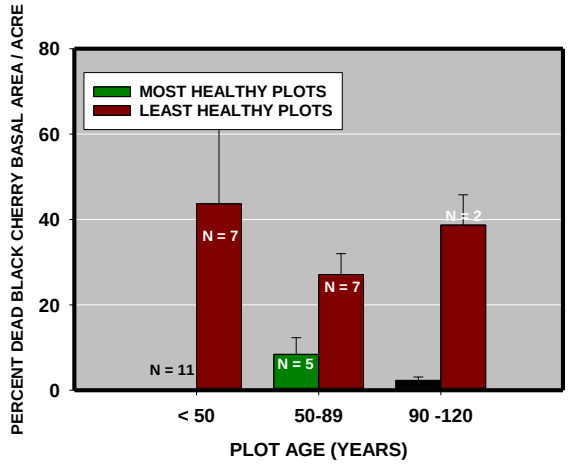

Figure 18. Mean percent dead black cherry basal area per acre by plot age class for the 16 most healthy and the 16 least healthy FHM plots.

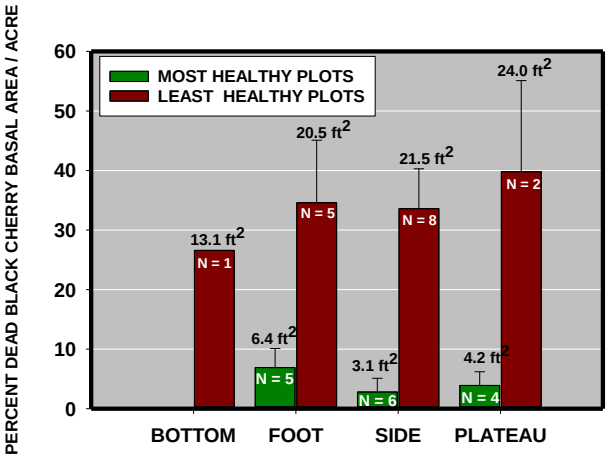

Figure 19. Mean percent dead black cherry basal area per acre by landform and slope position in the 16 most healthy and 16 least healthy FHM plots.

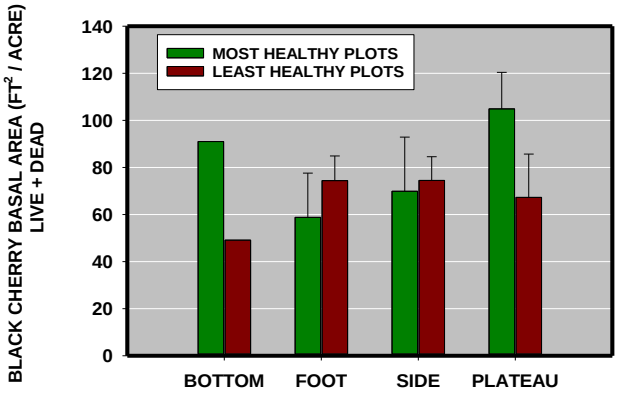

Figure 20. Amount of black cherry basal area per acre (ft^2/acre, live + dead trees) in four slope positions associated with FHM plots with contrasting black cherry health status.

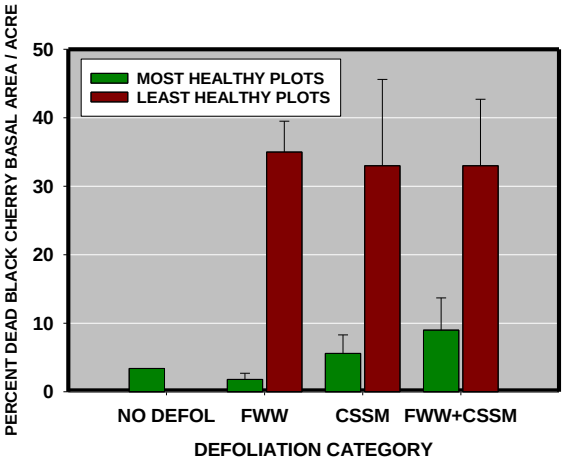

Figure 21. Mean percent dead black cherry basal by defoliation category in plots with contrasting black cherry health. FWW = 1-3 fall webworm defoliations; CSSM = 1–3 cherry scallop shell moth defoliations; FWW+CSSM = both FWW and CSSM defoliations.

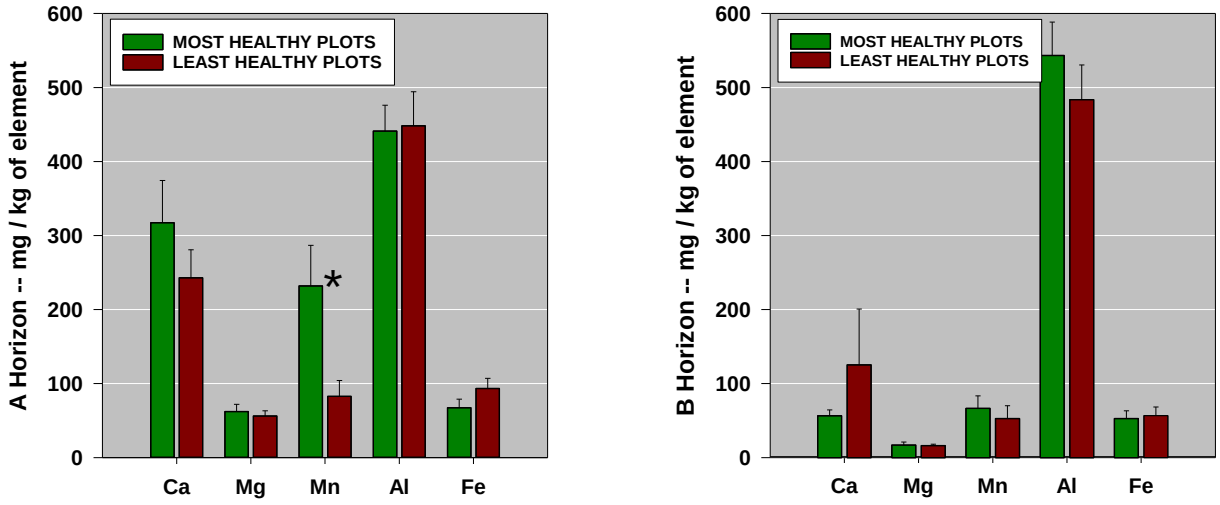

Figure 22. Exchangeable concentrations of Ca, Mg, Mn, Al, and Fe in A and B horizon mineral soils from the 16 most healthy and the 16 least healthy FHM plots. An asterisk above paired bars indicates a significant ($P \leq 0.05$) difference between the means.

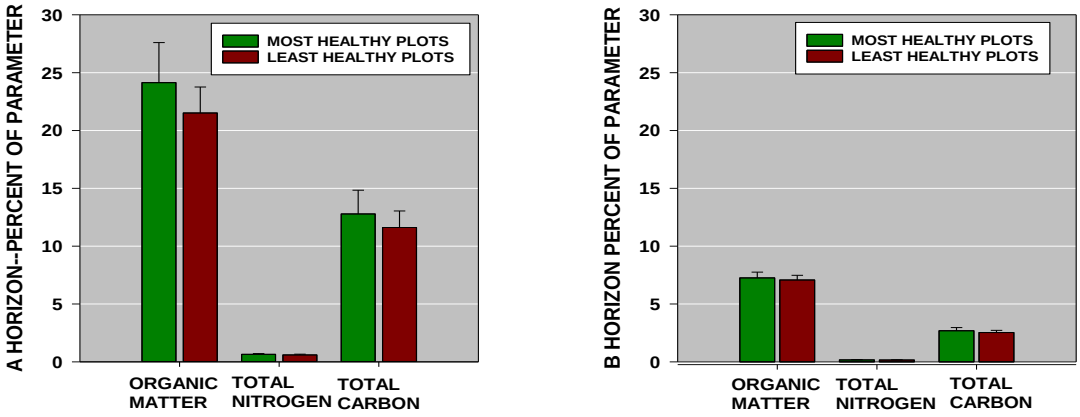

Figure 23. Percent organic matter (LOI), percent total N, and percent total C in A and B horizon mineral soil samples from FHM plots with contrasting black cherry health.